PERFORMANCE STUDIES OF A SINGLE VERTICAL BEAM HALO COLLIMATION SYSTEM AT ATF2

N. Fuster-Martínez, IFIC (CSIC-UV)*, Valencia, Spain
A. Faus-Golfe, IFIC (CSIC-UV), Valencia, Spain and LAL, Université Paris-Sud,Orsay, France
P. Bambade, R. Yang, S. Wallon, LAL, Université Paris-Sud, Orsay, France
I. Podadera, F. Toral CIEMAT, Madrid, Spain
K. Kubo, N. Terunuma, T. Okugi, T. Tauchi, KEK and SOKENDAI, Tsukuba, Japan

Abstract

In order to reduce the background that could limit the precision of the diagnostics located in the ATF2 post-IP beamline a single vertical beam halo collimation system was installed and commissioned in March 2016. In this paper, we present the measurements done in March and May 2016 in order to characterize the collimation system performance. Furthermore, the collimator wakefield impact has been measured and compared with theoretical calculations and numerical simulations in order to determine the most efficient operation mode of the collimation system in terms of halo cleaning and negligible wakefield impact.

INTRODUCTION

ATF2 is a scaled-down version of the Beam Delivery System (BDS) of the Future Linear Colliders (FLCs) Final Focus System (FFS) [1] built after the ATF Damping Ring (DR) (see Fig. 1). The ATF2 main objective is to achieve a vertical beam size at the virtual IP of 37 nm within a nanometer level stability.

The control and reduction of the beam halo distribution that could be intercepted by different components in the beamline producing undesired background is a crucial aspect for the FLCs and also for ATF2. In ATF2 the beam halo is formed mainly in the ATF DR and goes into the ATF2 beamline hitting at some locations the beam pipe. The most critical regions are the IP and post-IP were a Shintake monitor (IPBSM) is located used for measuring the nanometer vertical beam size (see Fig. 1). The IPBSM measures the modulation pattern photons produced in the interaction of a laser with the electron beam. Additional background photons in this region may be mixed with the IPBSM signal and limit its precision. Experimentally and by means of tracking simulations the vertical aperture of the last bending magnet (BDUMP) has been identified as the main source of background photons limiting the IPBSM signal to noise ratio. A transverse beam halo collimation system feasibility and design study for reducing the background in ATF2, specially in the last bending magnet, was done and reported in [2]. In March 2016, the vertical beam halo collimation system was installed and commissioned [3].

In this paper, we present the performance studies carried out in the ATF2 spring run. Secondly, we present the comparison of these measurements with realistic tracking simulations performed with the tracking code BDSIM [4]. Furthermore, the collimator wakefield impact on the orbit has been measured using the cavity BPMs system of ATF2 in order to verify the wakefield impact induced, to determine the optimum operation mode of the system and to perform benchmarking between analytical calculations, numerical simulations and measurements. These measurement are relevant for the FLCs because the ATF2 collimator design is based on a first mechanical design of the International Linear Collider (ILC) [5] spoilers. In addition, these measurements could be crucial to understand the discrepancies observed between measurements and predictions for similar geometries in the past experiments performed at ESA [6].

* Work supported by IDC-20101074, FPA2013-47883-C2-1-P and ANR-11-IDEX-0003-02

COLLIMATION EFFICIENCY STUDIES

The vertical collimation system was constructed and first tested at LAL without beam at the end of 2015. Then, in March 2016 the system was installed in ATF2 (see Fig. 2). More details about the installation and commissioning can be found in [3].

In the March and May 2016 runs the performance of the vertical collimation system with beam has been studied. First, beam halo measurements were performed with the post-IP Wire Scanner (WS) and the Diamond Sensor (DS) [7] located in the post-IP region to study the beam-jaws movement and alignment (see Fig. 1). During these runs the beam energy was 1.3 GeV, the intensity ranging from 0.1-1 $\times 10^{10}$ electrons per bunch and the optics configuration used was the $(10\beta_x^* \times 1\beta_y^*)$ being β_x^* and β_y^* the value of the nominal betatron functions at the IP. Fig. 3 shows the vertical beam halo distribution measured with the vertical DS with the collimator opened and close to 3 mm half aperture. The DS is located after the BDUMP as can be seen in Fig. 1. The DS measurements are limited by the BDUMP elliptical full aperture which is 26 mm in the vertical plane and 56 in the horizontal one. In order to observe the effect of the collimator on the DS we need to close the collimator at least to 4 mm.

The ATF2 studies required different beam and machine conditions. Because of that, the relative efficiency of the vertical collimation system has been studied for different beam intensities, DR vacuum pressures and ATF2 optics. The intensity ranging from 0.1-1 $\times 10^{10}$, the DR vacuum pressures was changed from $4.99 \times 10^{-7} Pa$ to $1.06 \times 10^{-6} Pa$ and the optics used were the nominal one $(10\beta_x^* \times 1\beta_y^*)$ and the

ISBN 978-3-95450-177-9

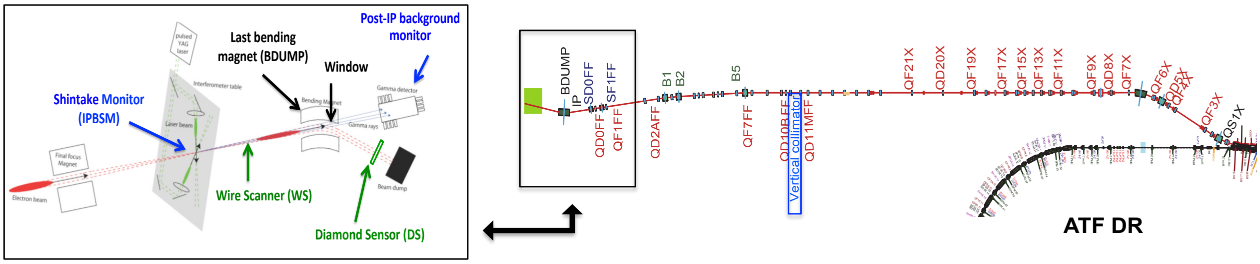

Figure 1: ATF and ATF2 layout with a zoom of the ATF2 post-IP beamline.

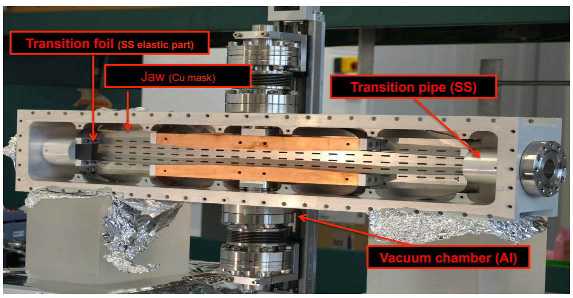

Figure 2: Vertical collimation system installed in ATF2.

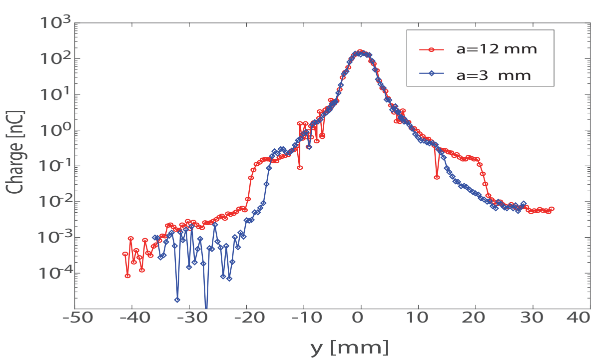

Figure 3: DS vertical beam halo distribution measurement.

so-called low beta optics ($10\beta_x^* \times 0.5\beta_y^*$). Measurements with the post-IP background monitor (CsI scintillator) and the post-IP Cherenkov monitor (used by the IPBSM monitor for beam size measurements) have been taken for different collimator apertures (both detectors are located in the post-IP beamline after the BDUMP as can be sen in Fig. 1). In all these scenarios the relative efficiency has been calculated in a relative way as the reduction of background photons as we close the collimator respect to the measured background level when the collimator is completely opened (vertical half aperture of 12 mm). In Fig. 4 is shown the relative reduction of background photons averaged over 100 pulses measured with the post-IP background monitor as a function of the half aperture of the collimator. The top plot of Fig. 4 shows the relative efficiency for three different intensities being the difference between the highest and the lowest intensity a 30 %, the middle plot shows the efficiency for the two DR vacuum pressures and the bottom plot the comparison for the two different optics studied. Notice that the negative values of the relative efficiency are due to the background fluctuations that can be caused by the interaction of the beam halo with other components along the beamline.

From these measurements we could conclude that for a variation of the intensity of about 30% the efficiency does not change. In the case of the DR vacuum pressure, for a worst vacuum scenario we observed a highest level of collimation relative efficiency. This is consistent with the DS transverse beam halo measurements performed in 2016 [8] showing an increase of the beam halo density and a change on the parametrization. In the case of the comparison for the two optics operation modes the difference observed on the relative efficiency is due to the increase of the beam size by a factor $\sqrt{2}$ in all the FFS.

Comparison with Realistic Simulations

Beam halo tracking simulations have been performed with MADX [9] and PLACET [10] tracking codes in order to optimize the location and study the efficiency of the vertical collimation system, the results were presented in [2]. These studies have been completed using the tracking code BDSIM an extension toolkit of Geant4 in order to study the efficiency of the collimator taking into account the emission of secondary particles and beam halo regeneration due to Electro Magnetic (EM) processes. The main goal of this study is to quantify the efficiency of the collimator in the reduction of photons that can reach the gamma detector of the IPBSM. The background generated by the collimator itself has also been studied in order to verify that the EM shower produced by the collimator does not generate additional background photons in the IP region. No additional background is expected at the IP and this is in agreement with the observations. More details can be found in [2] .

For the BDSIM simulations the ATF2 FFS line has been considered with ($10\beta_x^* \times 1\beta_y^*$) optics. A gaussian transverse beam halo distribution (x, x', y, y') with 10^6 electrons of 1.3 GeV has been generated from $\pm 3\sigma_{x,y}^{core}$ (only the beam halo tails are considered in these studies) with $\sigma_x^{halo} = 5\sigma_x^{core}$ and $\sigma_y^{halo} = 10\sigma_y^{core}$. No coupling between x-y planes has been taken into account. For the longitudinal distribution a gaussian model has been used with an energy spread of 0.08%. Multipoles and misalignments have not been taken into account. In Fig. 5 is shown the relative reduction of background photons generated in the BDUMP for different collimator half apertures at the BDUMP window for photons simulated and compared with the measurements performed

ISBN 978-3-95450-177-9

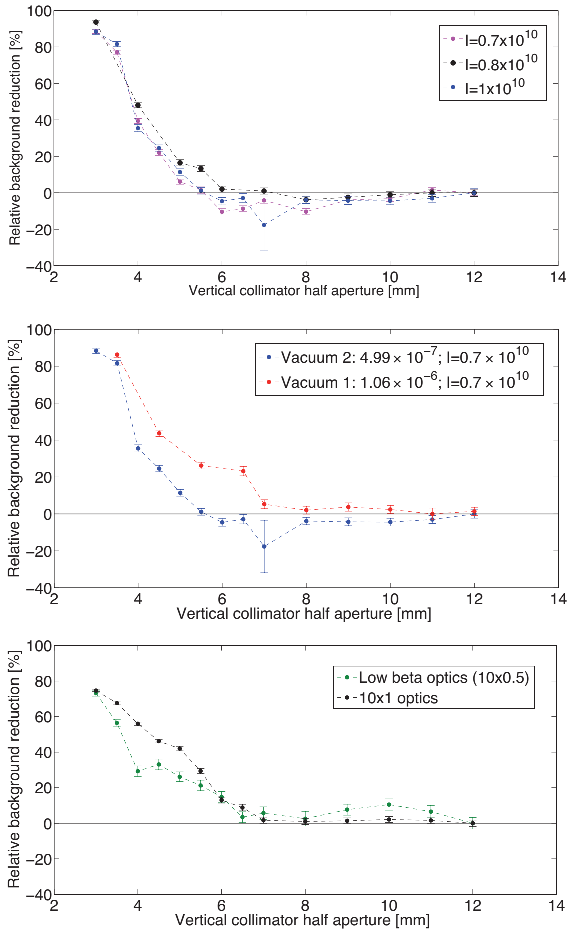

Figure 4: Relative efficiency for different intensities (top), DR vacuum pressures (middle) and optics (bottom).

with the background monitors. The comparison is compatible within the associated error for the two period runs (with the same beam and machine conditions) and the two detectors used.

It has been demonstrated that by adjusting the half aperture of the collimation system to a smaller aperture than 5 mm one can improve the IPBSM signal to noise ratio. However the collimator wakefield impact induced has to be considered when reducing the aperture of the collimator. In order to clarify this aspect and verify that we understand the wakefield impact induced by the collimator a measurements campaign have been carried out and the results are shown in the next section.

ORBIT COLLIMATOR WAKEFIELD IMPACT MEASUREMENTS

The wakefield impact induced in the vertical collimation system has been studied by means of analytical calculations, 3D EM simulations using CST PS [11] and tracking studies using a modified version of PLACET [12]. In order to complete the study the wakefield impact induced by the collimator on the beam orbit has been measured using the ATF2

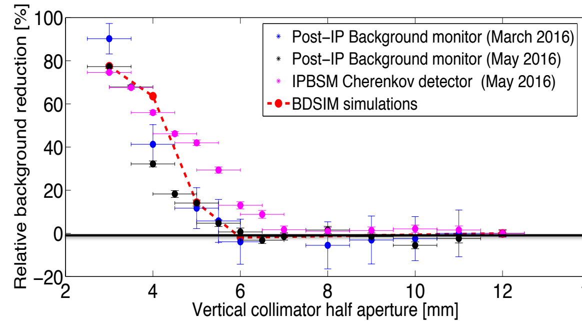

Figure 5: Comparison of the measured relative background reduction in the Post-IP region with the BDSIM simulations.

beam position monitors system formed by 45 C-band BPMs with 200 nm resolution in $\pm$ 1 mm range with 20 dB attenuation. In May 2016 run, orbit data have been taken for a fix collimator half aperture of 4 mm and different collimator offsets respect to the beam. Prior to the data analysis a study has been performed to select at which BPMs we expect to be able to observe a correlation between the measured beam position and the collimator offset. This selection is based on the BPMs resolution measured and the expected orbit variation, Δy, at each BPM using the kick factor calculated from the CST PS numerical simulations. The analysis of the orbit data have been performed following the procedure detailed in [13]. In order to subtract the orbit jitter, which is at the level of the expected collimator wakefield impact, the correlation between the collimator upstream and downstream BPMs has been calculated, X. Then, the residuals, $R = A'X - B'$, are calculated for each collimator offset where A' is the upstream BPMs readings, B' is the downstream BPMs readings. From the linear fit of the correlation between the collimator offset and the orbit change at each BPMs, R, the collimator wakefield kick, κ_T, can be estimated as [12]:

$$\kappa_T[\frac{V}{pCmm}] = \frac{p}{R_{34}[mm]}\frac{E[eV]}{eq[pC]} \quad (1)$$

where p is the slope of the linear fit, R_{34} is the corresponding transfer matrix element, E is the nominal ATF2 beam energy and eq is the measured charge of the beam.

Measurements have been taken in three different days in May 2016. During these runs the beam energy was 1.3 GeV, the intensity ranging from 0.9-0.95 $\times 10^{10}$ electrons per bunch and the optics configuration $(10\beta_x^* \times 1\beta_y^*)$. An example of the correlation observed at QF7FF C-BPM is depicted in Fig. 6. The resulting kick obtained at the different BPMs is depicted in Fig. 7 for the run on the 27th of May 2016. In green the expected value calculated using the analytical models is indicated and in red the one calculated from the numerical simulations. The bunch length was also measured using a Streak camera installed in the ATF DR in order to reduce uncertainties enabling the comparison of these results with simulations and analytical models which are bunch length dependent.

ISBN 978-3-95450-177-9

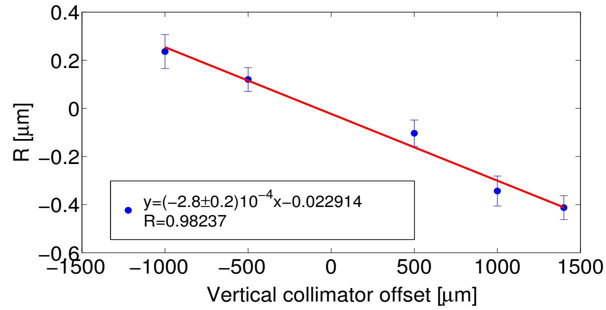

Figure 6: Residuals as a function of collimator offset from the 27th of May run at QF7FF.

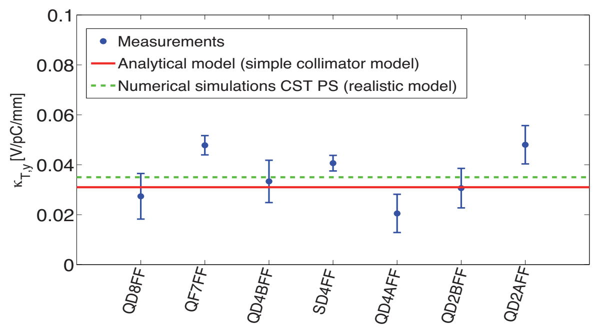

Figure 7: $\kappa_{T,y}$ reconstructed at different C-BPMs from the 27th of May run.

The weighted mean, $\bar{\kappa}_{T,y}$, of the three sets of measurements taken on the 22th, 25th and 27th of May is shown in Table 1 in comparison with the corresponding analytical and numerical calculation. These first measurements are compatible with

Table 1: Average $\bar{\kappa}_{T,y}$ and Comparison with Analytical and Numerical Calculations.

σ_z [mm]	$\kappa_{T,y}$ [V/pC/mm]		$\bar{\kappa}_{T,y}$ [V/pC/mm]
	Analytic	CST PS	Measured
9.6	0.031	0.035	0.038±0.002

the numerical simulations performed with CST PS within a 9 % and with the analytical calculation within a 23% for a bunch length of 9.6 mm. Notice here the difference on the model considered on the analytical calculations where only the jaws are considered while in the CST PS a realistic model has been simulated taken into account also de transition parts of the system and the connection to the beam pipe.

SUMMARY AND FUTURE WORK

A vertical collimation system has been installed in the ATF2 beamline. The efficiency of the collimator has been demonstrated by measuring the background photons with the post-IP background monitor. Furthermore, the relative efficiency has been studied and characterized under different beam intensities, DR vacuum pressures and ATF2 optics. The relative background photons reduction measured in the post-IP region as a function of the collimator half aperture is compatible with the simulations performed with the tracking code BDSIM. In addition, a first campaign of collimator wakefield impact measurements on the orbit has been carried out for 4 mm half aperture. The wakefield kick obtained from these first measurements is compatible with the numerical simulations within a 9 % and with the analytical calculation within a 23%. A second campaign of wakefield measurements is planned in the fall run in order to confirm these results.

ACKNOWLEDGMENTS

We gratefully acknowledge J. Snuverink, L. Nevay and S. Boogert for their contribution with the BDSIM and the wakefield kick analysis. Also we would like to thanks G. White, A. Schuetz, and M. Stanitzki for their help on the experimental tests performed at ATF2.

REFERENCES

[1] G. R. White et al., "Experimental Validation of a Novel Compact Focusing Scheme for Future Energy Frontier Linear Lepton Colliders", Phys. Rev. Lett. 112,034802, 2014

[2] N. Fuster-Martínez, A. Faus-Golfe, J. Resta-López, P. Bambade, S. Liu, S. Wallon, F. Toral, I. Podadera, K. Kubo, N. Terenuma, T. Okugi, T. Tauchi,"Design study and construction of a transverse halo collimation system", IPAC15, WEPMN059

[3] N. Fuster- Martínez, A. Faus-Golfe, J. Resta- López, P. Bambade, R. Yang, S. Wallon. F. Toral, I. Podadera, K. Kubo, N. terunuma, T. Okugi, T. Tauchi. Commissioning and first performance studies of a single vertical beam halo collimation system at ATF2", IPAC16, THPOR030

[4] `http://twiki.ph.rhul.ac.uk/twiki/bin/view/PP/JAI/BdSim`

[5] TDR, ILC-TDREPORT-2013

[6] J. L. Fernandez-Hernando, , S. Molloy, J.D.A. Smith, N. K. Watson, "Measurements of collimator wakefields at End Station A", EPAC08, WEPP163

[7] S. Liu, P. Bambade,F. Bogard, P. Cornebise, V. Kubytskyi, C. Sylvia, A. Faus-Golfe, N. Fuster-Martinez, T. Tauchi, N. Terenuma,"Investigation of beam halo using in vacuum diamond sensor at ATF2", IPAC15, THPOR030

[8] R.J. Yang, P. Bambade, V. Kubytskyi, A. Faus-Golfe, N. Fuster-Martínez T. Naito, "Modeling and Experimental Studies of Beam Halo at ATF2", IPAC16, MOPMB008,

[9] `http://mad.web.cern.ch/mad`

[10] A. Latina, Y. Levinsen, D. Schulte, J. Snuverink, "Evolution of the tracking code Placet", IPAC13, MOPWO053

[11] https://www.cst.com/products/cstps

[12] N. Fuster-Martínez, A. Faus-Golfe, A. Latina, J. Snuverink, "Geometric wakefield regimes study of a rectangular tapered collimator for ATF2", ATF2-01-2016

[13] J. Snuverink, R. Ainsworth, S.T. Boogert, F. J. Cullinan, A. Lyapin, Y. I, Kim, K. Kubo, T. Okugui, T. Tauchi, N. Terunuma, J. Urakawa, G. R. White, "Simulations and measurements of wake fields at the Accelerator Test Facility 2", PRST-AB submitted to be published

ISBN 978-3-95450-177-9